Introduction to LTE Advanced Pro (4.5G)

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Slides and Audio/Video recordings of this class lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-20/

Student Questions

Overview

1. What is LTE Advanced Pro?
2. LTE Advanced Pro Features in 3GPP Release 13
3. LTE Advanced Pro Features in 3GPP Release 14

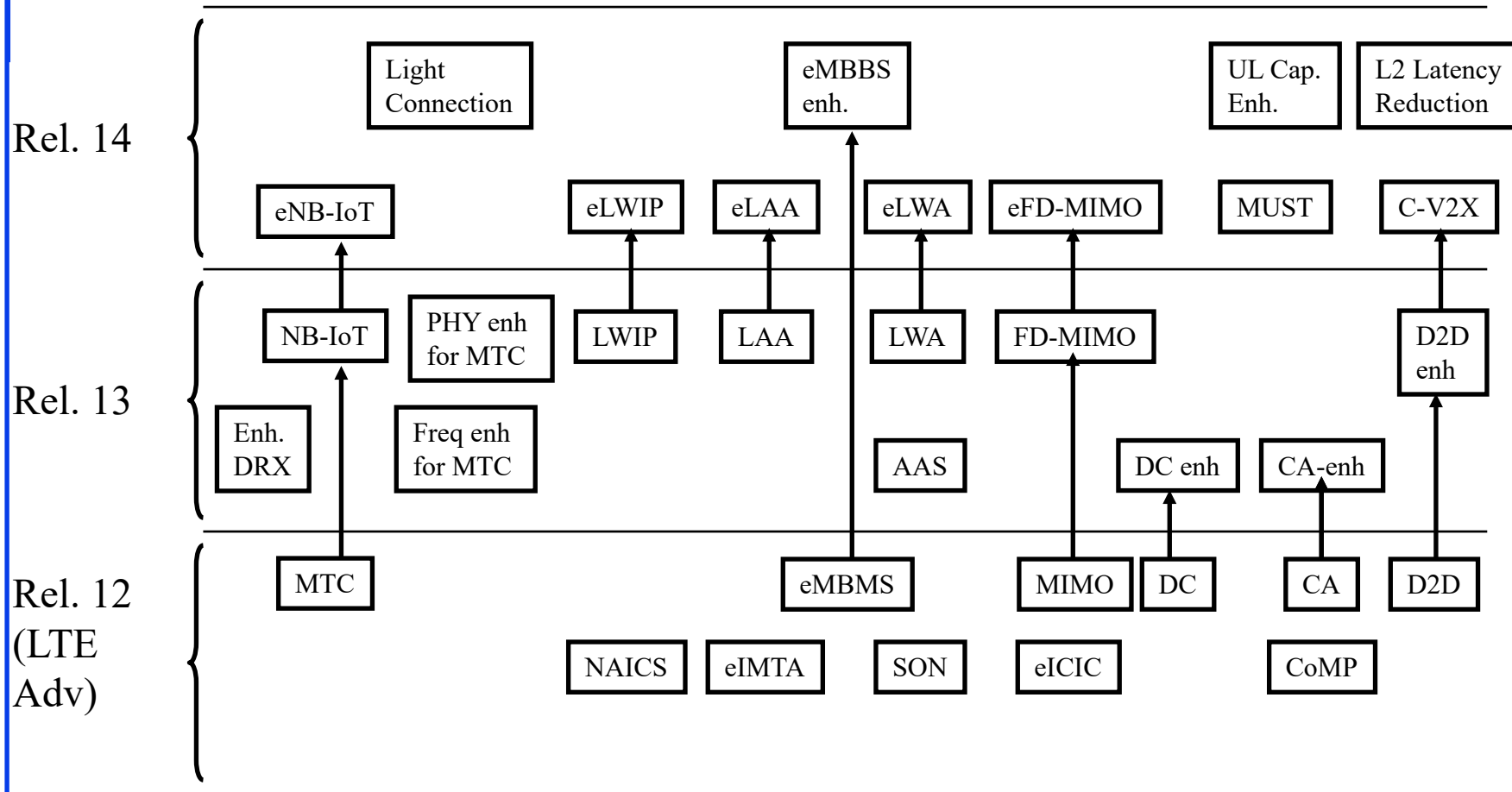Note: This is the 4th module in a series of lectures on 1G to 5G. 5G is covered in the next module.

Student Questions

3GPP Releases

- **Rel. 8-9**: LTE
- **Rel. 10-12**: LTE-Advanced (4G)
- **Rel. 13-14**: LTE Advanced-Pro (**4.5G**)
- **Rel. 15-16**: LTE NR (5G)

Student Questions

LTE Advanced Pro

Rel. 14

| Light Connection | | eMBBS enh. | | UL Cap. Enh. | L2 Latency Reduction |

| eNB-IoT | | eLWIP | eLAA | eLWA | eFD-MIMO | MUST | C-V2X |

Rel. 13

| NB-IoT | PHY enh for MTC | LWIP | LAA | LWA | FD-MIMO | | D2D enh |

| Enh. DRX | Freq enh for MTC | | | AAS | | DC enh | CA-enh |

Rel. 12 (LTE Adv)

| MTC | | eMBMS | MIMO | DC | CA | D2D |

| NAICS | eIMTA | SON | eICIC | CoMP |

Student Questions

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Release 13 Features

1. Active Antenna Systems (AAS)
2. Self-Organizing Networks (SON)
3. Elevation Beamforming
4. Inter-eNB CoMP
5. Indoor Positioning
6. Carrier Aggregation Enhancements
7. License Assisted Access (LAA)
8. LTE-WLAN Aggregation Enhancements
9. Wi-Fi with IP Flow Mobility
10. RAN Sharing
11. Enhanced D2D Proximity Services (PROSE)
12. Dual Connectivity Enhancements
13. MTC Enhancements
14. Single-Cell Point-to-Multipoint (SC-PTM)

Student Questions

Release 14 Features

1. Enhance Narrowband IoT (eNB-IoT)
2. Enhanced Machine Type Communications (eMTC)
3. Enhanced LWIP (eLWIP)
4. Enhanced LTE-WLAN Aggregation (eLWA)
5. Enhanced License Assisted Access (eLAA)
6. Enhanced Full-Dimension (eFD) MIMO
7. Enhanced Multimedia Broadcast Multicast Service (eMBMS)
8. **Multiuser Superposition Transmission (MUST)**
9. **Layer 2 (L2) Latency Reduction**
10. **Vehicle to Vehicle (V2X) Based on Sidelink**
11. Uplink (UL) Capacity Enhancements
12. Light Connection

Student Questions

Active Antenna Systems (AAS)

❑ Antenna + Transceiver combined ⇒ Active Antenna

❑ Allows Active antenna arrays

  ➢ Produce dynamically adjustable radiation patterns depending upon the current traffic

  ➢ Beam footprint can be adjusted (beamforming)

  ➢ Cell edge can be adapted to load demand

  ➢ Dynamic Cell Splitting: Vertical or horizontal sectors and/or Smaller footprints ⇒ Reduced real-estate costs

  ➢ Software reconfigurations allow easy evolution

❑ Allows multi radio access technologies

❑ Allows combining local and wide area technologies

Student Questions

Self-Organizing Networks (SON)

❑ For AAS based deployments

❑ Parameters are now dynamically computed and applied

❑ Previous releases had static optimization.
Release 13 extended to dynamic optimization

❑ eNB can now signal to neighboring cells any changes in configuration

❑ Planned changes are notified in advance to avoid failures

Student Questions

Elevation Beamforming

❑ Aka 3D-MIMO or Full-dimension MIMO (**FD-MIMO**)

❑ Infinite Antennas = **Massive MIMO**

❑ Require appropriately coded Channel State Information Reference signals (CSI-RS) and Sounding Reference Signals (SRS), and demodulation reference signals (DMRS)

❑ 16 Antennas in R13, 32 in R14

FD-MIMO simultaneously supports elevation & azimuth beamforming and > 10 UEs MU-MIMO
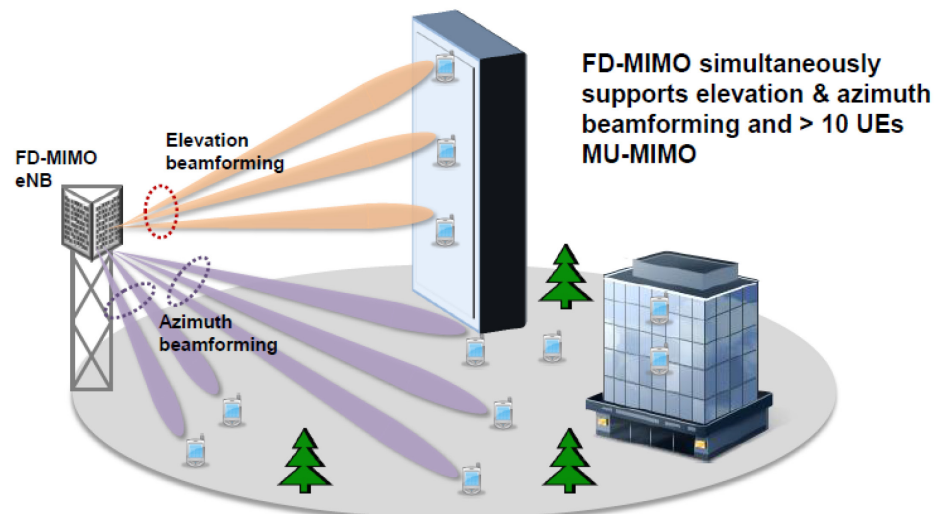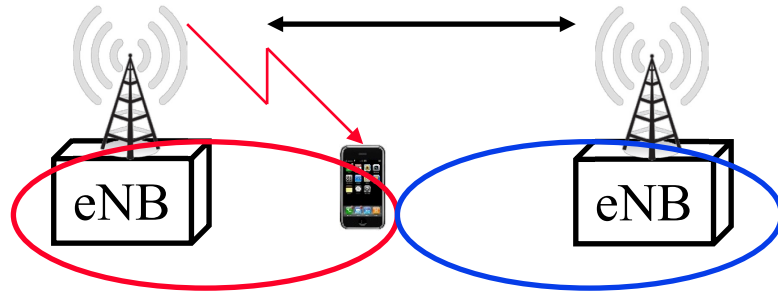
Student Questions

Ref: G. Xu, et al, "Full-Dimension MIMO: Status and Challenges in Design and Implementation," May 2014, http://www.ieee-ctw.org/2014/slides/session3/CTW_2014_Samsung_FD-MIMO.pdf

Inter-eNB CoMP

❑ Coordinated Multipoint Operation (CoMP) in Release 11 was restricted to eNBs connected via ideal backhaul
$\Rightarrow$ No need for network interfaces

❑ In Release 12, a signaling interface has been added which allows eNBs to interchange measurement and resource allocation information

❑ In Release 13, new signaling elements were added

Student Questions

Machine Type Communication

❑ **LTE Low-cast (Category 0) UE**: In Release 12.
  ➢ Single Antenna
  ➢ Reduced peak rate up to 1 Mbps
  ➢ Half-Duplex $\Rightarrow$ No duplex filter
  ➢ Power saving mode (PSM)

❑ **MTC LTE (LTE Cat-M1)** UE: In Release 13.
  ➢ 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
  ➢ All power on fewer subcarriers
    $\Rightarrow$ **P**ower **S**pectral **D**ensity (**PSD**) Boosting
    $\Rightarrow$ 15 dB reduction in link budget by PSD and repetition
    $\Rightarrow$ Allows UEs in basements and indoors
  ➢ Reduced Tx power to 20 dBm $\Rightarrow$ integrated amplifier
  ➢ Popular in North America

❑ **Narrow Band IoT** (NB-IoT or **LTE Cat-NB1**) introduced Category -2 UE:
  ➢ 128 kbps using 200 kHz band = Single PRB
  ➢ 23 dBm power (required to maintain the link budget)
  ➢ Most promising IoT protocol. Already in use in China. Popular in Europe.

❑ Both LTE-M and NB-LTE UEs use single RF chain

Student Questions

❑ Can you clarify what you mean by "link budget" in Narrow Band IoT?
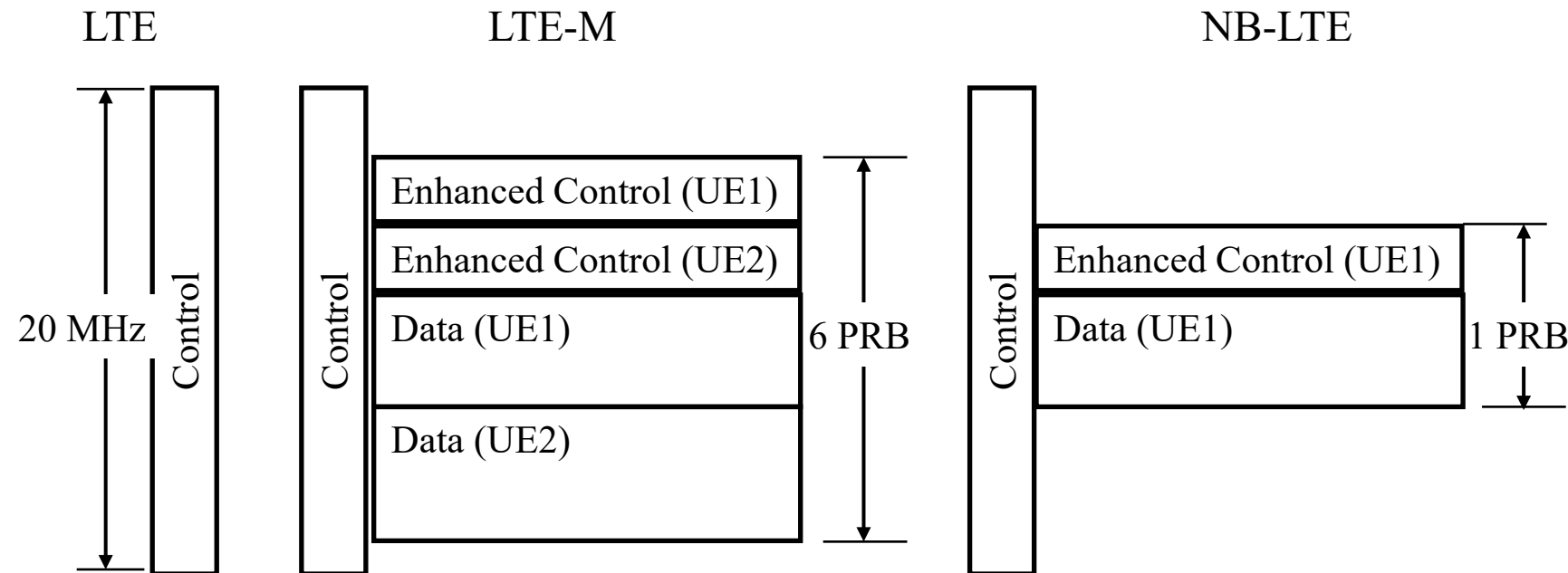
Link Budget = Allowed power loss in the link
=Transmit power – Received power
If a receiver is not sensitive, it needs a larger receive power. Therefore, we need a large transmit power too.

Signaling Enhancements for MTC

❑ **E**nhanced **P**hysical **D**ownlink **C**ontrol **Ch**annel (EPDCCH)

❑ LTE Cat 0 UE receive signaling in the entire 20 MHz band

❑ LTE-M UEs receive signaling in their 1.4 MHz band

❑ For NB-LTE UEs, signaling is part of the assigned PRB

LTE   LTE-M   NB-LTE

20 MHz	Control	Control	Enhanced Control (UE1)	6 PRB

Enhanced Control (UE1)
Enhanced Control (UE2)
Data (UE1)
Data (UE2)

Control
Enhanced Control (UE1)
Data (UE1)
1 PRB

Power Saving Mode (PSM)

❑ Discontinuous Reception (DRX). Introduced in Release 12

❑ Allows UE to stay registered while sleeping

❑ UE's need to monitor resource allocation channel even if it has nothing to send or receive

❑ Connected mode DRX (cDRX): UE can sleep and periodically wake up to check the control channel

  ➢ Short sleep cycle: 5 to 400 ms

  ➢ Long sleep cycle: 20 ms to 2.5s
    (if no activity for 4 short cycles)

Active

Sleep ⟶   Short   Long

Student Questions

Indoor Positioning

❑ FCC requires indoor positioning for E911
  ➢ x/y location within 50 m by 2021
  ➢ Provide z location by 2023
❑ Position can be determined by:
  ➢ Barometric sensors
  ➢ Wireless LANs
  ➢ Bluetooth beacons
  ➢ Terrestrial beacon system broadcasting signals for positioning, e.g., Metropolitan Beacon Systems (MBS)
❑ R13 supports only standalone mode and UE assisted mode without network assistance are supported. Only MBS is supported.
❑ R14 introduced advanced techniques using Enhanced Cell-ID and Observed Time Difference of Arrival.

Student Questions

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Carrier Aggregation Enhancements

❑ CA was introduced in R10

❑ R12 limited to 5 carriers $\Rightarrow$ 100 MHz

❑ R13 extended to 32 carriers $\Rightarrow$ 640 MHz

  ➢ Both FDD and TDD

  ➢ Inter-band and Intra-band

  ➢ Licensed and Unlicensed

❑ 64-QAM can be used with carrier aggregation

Student Questions

License Assisted Access (LAA)

❑ 5 GHz band for public hot-spots and in-building
❑ Different rules and bands in different countries, e.g.,
  ➢ Avoid if a radar is operating
  ➢ Can't block 20 MHz if using only 180 kHz
  ➢ Transmit only if free. Recheck after maximum occupancy time ⇒ Can not transmit continuously as in standard LTE
❑ Carrier aggregation with unlicensed band and licensed band when possible. DL enhancement in R13. UL enhancements in R14.

Student Questions

200 mW or less   1W

USA

Europe/Japan

China

5150   5350   5470   5725   5850
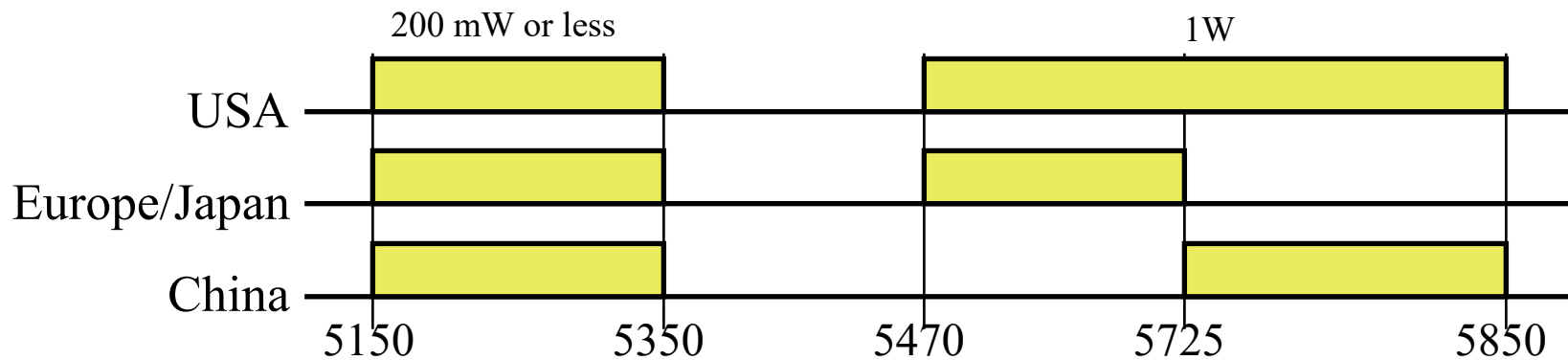
LAA (Cont)

❏ End-to-End LTE $\Rightarrow$ Better integration than with Wi-Fi

❏ Before R13, several different solutions called LTE-U were used.

❏ R13 introduced a global standard to include 5 GHz unlicensed band using several 20 MHz channels

❏ To coexist with Wi-Fi, LAA uses

- ➢ Listen before talk

- ➢ Discontinuous transmission on a carrier with limited maximum transmission duration

- ➢ Dynamic frequency selection to avoid interference with radar systems in some regions

- ➢ Multicarrier transmission across multiple unlicensed channels

Student Questions

LTE-WLAN Aggregation Enhancements

❑ LTE-WLAN aggregation (LWA) was introduced in R12

❑ In R13:

  ➢ LTE_WLAN Radio Level Integration with IPSec tunnel (LWIP) allows both uplink and downlink traffic to be sent over WLAN

  ➢ RAN Controlled LTE-WLAN interworking (RCLWL) allows eNB to send traffic steering commands to UE based on UE measurements

Student Questions

Wi-Fi with IP Flow Mobility

❑ Network Based Internet Protocol Flow Mobility (NBIFOM)

❑ IP flows can be steered towards PDN or Wi-Fi

❑ Trusted and untrusted WLAN interfaces have been defined.

❑ Similar to but different from LTE-WLAN aggregation (LWA)

❑ Even Voice and Video traffic can be sent over Wi-Fi
  $\Rightarrow$ Allows increased coverage area
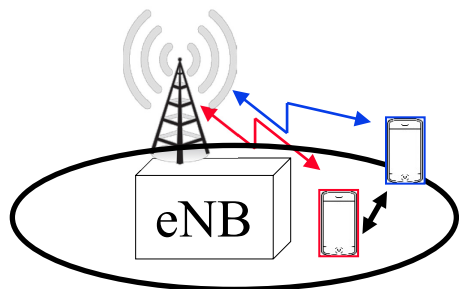
Student Questions

RAN Sharing

❑ Multiple operators can share a radio access network (RAN)

❑ Each operator runs a "Public Land Mobile Network (PLMN)"

❑ Owner operator can put limits on total UL/DL load of sharing PLMNs
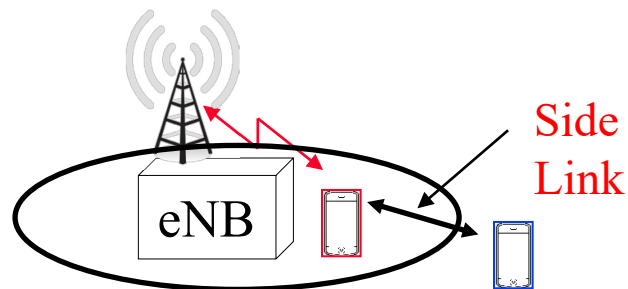
❑ QoS profile can also be limited as agreed

Student Questions

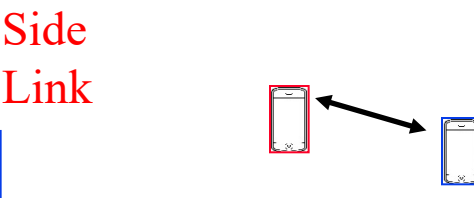©2020 Raj Jain

Enhanced D2D Proximity Services (PROSE)

❑ Device-to-Device (D2D) was introduced in R12

❑ In R13:

  ➢ UEs can search multiple PLMNs for "side-link"

  ➢ Out-of-coverage D2D discovery

  ➢ Support for relaying using D2D. L3 relay was defined. Public safety personnel can connect to network through other mobiles.

(a)   (b)   (c) First Responders only

Side Link

Dual Connectivity Enhancements

❑ Dual connectivity was introduced in R12
Allowed only downlink throughput enhancement

❑ In R13:

  ➢ Uplink bearer split

  ➢ UE splits the traffic only if the queue is over a threshold

  ➢ Timing differences between two bears is handled
      $\Rightarrow$ Allows dual connectivity to different operators

  ➢ Traffic steering is supported.
      Local traffic and Selective IP traffic can be directed towards
      small cell to avoid overloading core network

Student Questions

Extended Discontinuous Reception (DRX)

❑ Power Saving Mode (PSM) was introduced in R12 to allow IoT devices to save power. Requires frequent periodic registration.

❑ In R13:

   ➢ Idle mode DRX cycles can be extended to 45 minutes for (for non-NB-IoT) or 3 hours for NB-IoT

   ➢ Active mode DRX cycle can be extended to 10 s

❑ User Element (UE) States:

   ➢ **Disconnected**: All electronics off. Will not ring if called.

   ➢ **Power Saving Mode**: Sleeping. Most electronics off. Will ring if called.

   ➢ **Idle Mode**: Nothing to send/receive. Some electronics off. Keeps track of towers if moving.

   ➢ **Active Mode**: Transmitting/receiving. Electronics are on. DRX allows some parts off during pauses.
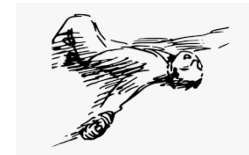
Student Questions

❑ Is the action sending done during idle mode or active mode? You said during sending you can sleep but I wasn't sure if sleep = idle?

Slide updated

LTE Cat-M1

- For machine type communication in Release 13.
- 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
- Signaling inside 1.4 MHz $\Rightarrow$ Do not need to listen to 20 MHz
- All power on fewer subcarriers
  $\Rightarrow$ **P**ower **S**pectral **D**ensity (**PSD**) Boosting
  $\Rightarrow$ 15 dB reduction in link budget by PSD and repetition
  $\Rightarrow$ Allows UEs in basements and indoors
- Reduced Tx power to 20 dBm
  $\Rightarrow$ integrated amplifier
- Popular in North America

Student Questions

- What is a physical resource block?

LTE Slide 17-20
Minimum allocation is 12 carriers for one slot
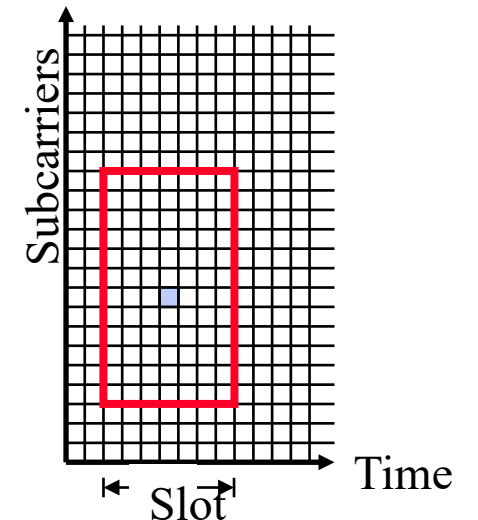
Cat-0 vs. Cat-M1

	Cat -0	Cat -M 1
Downlink	64 -QAM	16 -QAM
Uplink	16 -QAM	16 -QAM
Bandwidth	Full	1.08 MHz
Peak Rate	1Mbps (DL/UL)	1 Mbps (DL/UL)
Power Classes	23 dBm	23 dBm, 20 dBm
Path loss	140.7 dB	155.7 dB

Not used

Ref: P. Reininger, "3GPP Standards for the Internet-of-Things," Presentation at Smart Summit Singapore, Nov 2016, 17 pp.,
https://tinyurl.com/3gpprel13

Student Questions

❑ Is the M1 category designed for sensors because of the UL peak rate is higher than DL peak rate?
Slide has been updated.

❑ Why is the downlink less than uplink? You also mentioned that bandwidth needs to be changed from 1.08 MHz to something, what should it be changed to?
It is 1.08 MHz.

Narrow Band IoT (NB-IoT)

❑ **LTE Cat-NB1** or Category -2 UE also in Release 13.

❑ Designed for ultra-low cost (<$5), low data rate, high power efficiency, deep in house coverage
  ➢ No handovers while active
  ➢ No channel measurements
  ➢ No MIMO
  ➢ QPSK or BPSK
  ➢ Single RF Chain $\Rightarrow$ Half-duplex
  ➢ Data repetition to enable deep in-house coverage

❑ 15 uW in idle state, 500 mW in transmitting.
  A 5 W-hr battery will last 10 years

❑ Most promising IoT protocol. Already in use in China. Popular in Europe.

Ref: Hossam Fattah, "5G LTE Narrowband Internet of Things (NB-IoT)," CRC Press, Boca Raton, 3 September 2018, 262 pp., ISBN 9780429847585
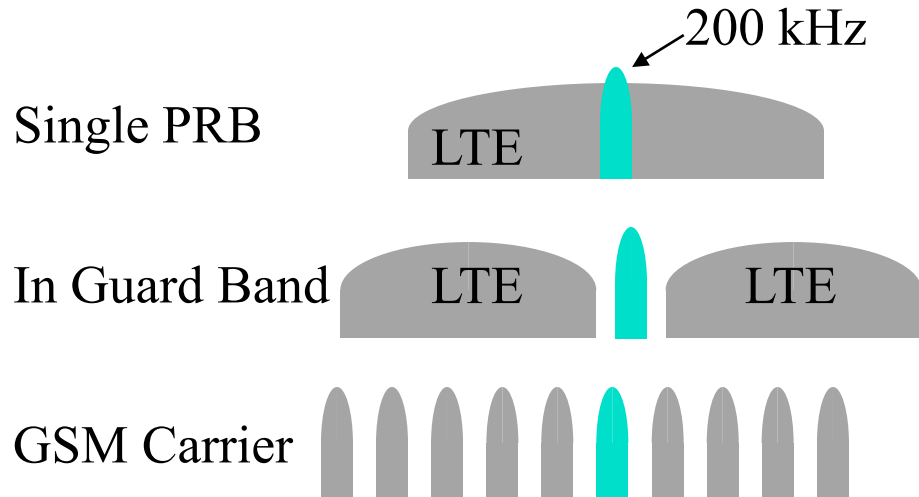

Student Questions

❑ What is meant by "no handover when active"? You need to reboot if you want to connect to a new master device? Or just no handover during a transmission.

IoT devices cannot move while they have active connection. They have to disconnect, move if needed, and reconnect.

Band for NB-IoT

- 128 kbps using 180 kHz band = Single PRB of 12 subcarriers (12 tones)
- Can be in-band, in guard-band, or out-of-band using 200 kHz GSM carrier
- All 3 deployments invisible to non-NB-IoT devices
- Optionally concentrate power in 3.75 kHz tone to allow longer distance transmissions.
- All 12 tones in DL.
  1, 3, 6, or 12 tones in UL.

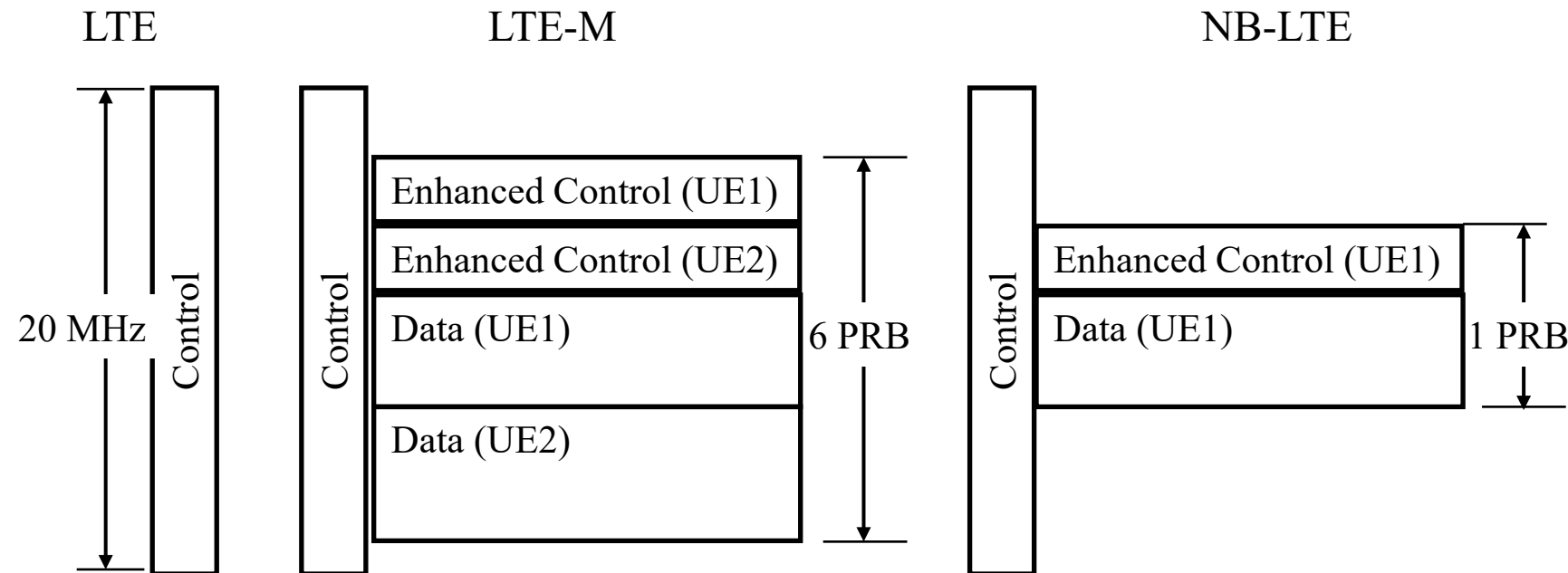**Student Questions**

- What exactly is a "tone"?
subcarrier

Single PRB

In Guard Band

GSM Carrier

200 kHz

LTE

LTE   LTE

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Signaling Enhancements for MTC

❑ **E**nhanced **P**hysical **D**ownlink **C**ontrol **Ch**annel (EPDCCH)

❑ LTE Cat 0 UE receive signaling in the entire 20 MHz band

❑ LTE-M UEs receive signaling in their 1.4 MHz band

❑ For NB-LTE UEs, signaling is part of the assigned PRB

LTE   LTE-M   NB-LTE

20 MHz | Control | Control

Enhanced Control (UE1)
Enhanced Control (UE2)
Data (UE1)
Data (UE2)
6 PRB

Control

Enhanced Control (UE1)
Data (UE1)
1 PRB

Carriers for NB-IoT

Student Questions

❑ Several NB-IoT channels/carriers per sector. One anchor carrier used to broadcast system information, control, and shared channels.

❑ All devices in idle state camp on this anchor carrier. Can be scheduled to receive/transmit on non-anchor carriers.

❑ Can serve up to 50,000 devices per sector

❑ In R13, paging and random access only on anchor carriers
In R14, this can be done on non-anchor carriers also.

❑ In R13, two UE power classes: 20 dBm and 23 dBm
In R14, one more UE power class with 14 dBm

NB1 Energy Saving Mechanisms

- **Extended Idle Mode Discontinuous Reception (eDRX):**
  - ➢ Normal LTE devices listen to paging every 1.28s in idle state.
  - ➢ NB1 devices can request to extend this to 5.12s to 43.69 minutes. If the network accepts, the device can power off for that long without loosing its state including IP address.

- **Power Save Mode**: LTE devices have to perform periodic tracking area updates. NB1 devices can extend this update timer to several days.

- **Control Plane CIoT EPS Optimization**:
  NB1 user data can be sent/received in control channels
  ⇒ No need to schedule user data bearer

- **Non-IP Data Delivery (NIDD):** A Service Capability Exposure Function (SCEF) encapsulates/decapsulates IP packets and sends/receives data without IP headers to/from NB1 device

Student Questions

MTC Enhancements in R14

❑ More accurate positioning

❑ Multicast to several UEs

❑ Improvement to VoLTE speech with enhanced coverage
  Packet bundling at application and MAC layers

❑ Higher data rates: Cat NB2

  ➢ 2536 bits per transmission in UL and DL
    compared to 1000 bits in UL and 680 bits in DL for NB1

  ➢ Two HARQ processes in stead of one

  ➢ 127 kbps in DL and 159 kbps in UL

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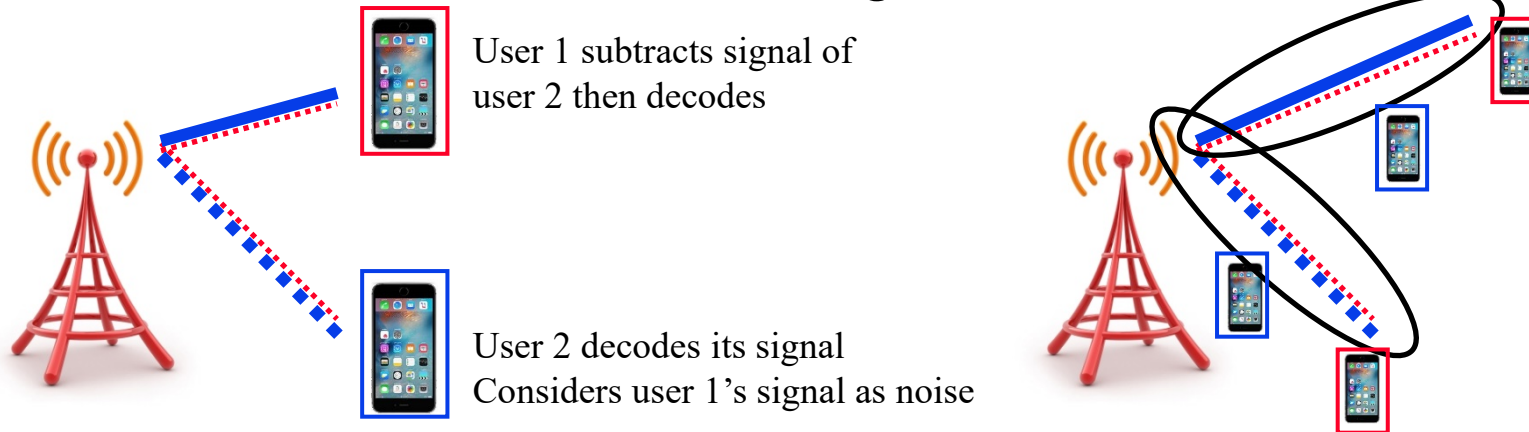©2020 Raj Jain

Single-Cell Point-to-Multipoint (SC-PTM)

❑ Enhancement of enhanced Multimedia Multicast Broadcast (eMBMS)

❑ eMBMS allows multi-cell broadcasts but requires synchronization among eNBs.

❑ SC-PTM does not require synchronized networks as in eMBMS

❑ Each cell handles it's own broadcasts.

❑ A physical downlink shared channel (PDSCH) is used

❑ Control information is broadcast on a "single-cell multicast control channel (SC-MCCH). Indicates active MBMS sessions and information about each session

❑ Data is broadcast on a "Single Cell multicast transport channel (SC-MTCH).

❑ In R14, SC-PTM was extended to NB-IoT devices

Student Questions

Multi-User Superposition Transmission (MUST)

❑ Users are distinguished by power levels
  Non-Orthogonal Multiple Access (NOMA)
❑ Users with poor channel condition get higher power
❑ Users with higher power decode their signal treating others as noise
❑ Users with lower power subtract the higher powered signals before decoding.
❑ Can also be used with beamforming and MIMO

User 1 subtracts signal of user 2 then decodes

User 2 decodes its signal
Considers user 1's signal as noise

Ref: G. Ding, et al, "Application of Non-orthogonal Multiple Access in LTE and 5G Networks,"
https://pdfs.semanticscholar.org/a404/21a9762db528bfe848166765fee43e740c94.pdf

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Student Questions

L2 Latency Reduction

❑ Instant Uplink Access (IUA): A.k.a Fast up link
- ➢ A long-lasting grant with recurring resources is provided to the device
- ➢ Extension of Semi-Persistent Scheduling (SPS) with shorter recurring periods of up to 1 ms
- ➢ Device transmits only if there is data
  Does not need to transmit padding if there is no data
  $\Rightarrow$ Saves power
- ➢ eNB sends Nack if no data is received during a scheduled grant

❑ Short Transmit-time Travel Interval (TTI):
- ➢ Time to switchover from receive to transmit
- ➢ 2 symbols for FDD, 7 symbols for TDD

Student Questions

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Cellular Vehicle-to-X (C-V2X)

❑ Vehicle-to-Vehicle (V2V): Collision avoidance

❑ Vehicle-to-Infrastructure (V2I): Traffic lights

❑ Vehicle-to-Pedestrians (V2P): Safety alerts

❑ Vehicle-to-Network (V2N): Maps, routing

❑ Use 5.9 GHz VANET spectrum direct PC5 interface for V2I, V2P, V2V

❑ Use licensed spectrum for V2N

❑ Direct communication using enhanced LTE D2D sidelink w PC5 Interface

❑ Another alternative is to use UE to eNB Uu interface for upload and retransmission/broadcast from eNB
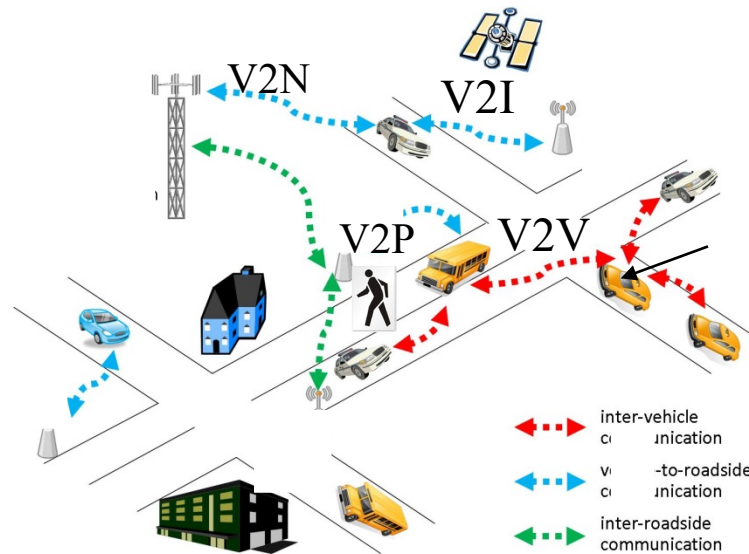
Student Questions

Ref: Qualcomm, "Expanding the 5G NR ecosystem and roadmap in 3GPP Release 16 and beyond," Sep 2018, 35 pp.,
https://www.qualcomm.com/media/documents/files/expanding-the-5g-nr-ecosystem-and-roadmap-in-3gpp-rel-16-beyond.pdf

D2D vs. V2V

	D2D	V2V
Application	Voice	M2M
Packet Size	Small	Large
Latency	Not Critical	Critical 20-100 ms
UE Density	Low # of safety personnel	High number of vehicles
Dynamics	Pedestrian speeds	250 km/h

Student Questions

V2V Extensions

❏ Higher Doppler due to high speed: Doubled the number of demodulation reference symbols (DMRS) to 4

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

1 slot

Reference Signal
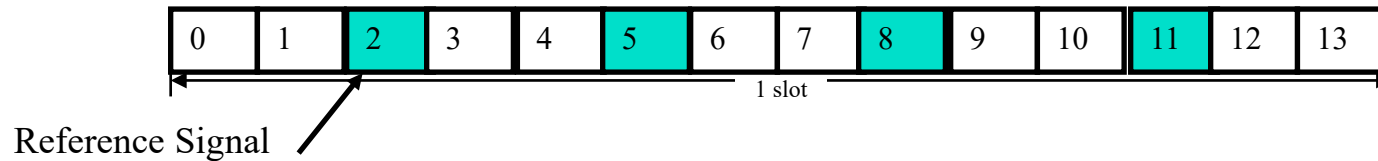
❏ Lower Latency: Scheduling and data in the same subframe

❏ Collision Avoidance: UEs can sense load on the channel and request resources in advance to avoid collisions

❏ Global Navigation Satellite Systems (GNSS) based Synchronization: V2V almost always have GPS. It can be used in addition to eNB timing.

❏ Enhanced sidelink configuration and signaling

Student Questions

Summary

1. LTE Advanced Pro is 4.5G technology developed by 3GPP as Release 13 and 14

2. Release 13 introduced several new features:

   1. AAS and FD-MIMO

   2. Spectrum Aggregation enhancements: LAA, LWA, LWIP

   3. IoT/MTC

   4. D2D for Safety personnel

3. Release 14 mostly further enhanced these features and added:

   1. MUST

   2. V2X

Student Questions

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Reading List

1. Rohde & Schwarz, "LTE-Advanced Pro Introduction eMBB Technology Components in 3GPP Release 13/14," White paper, 50 pp., https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/LTE-Advanced-Pro_Introduction_White_paper_en_5215-8258-52_v0100.pdf

2. G. Pfeifer, "5G Technology Introduction, Market Status Overview and Worldwide Trials," 5G and IoT Seminar, Italy, May 2017, https://cdn.rohde-schwarz.com/it/seminario/5G_Seminar_Part1_Standardization_Market_PHY_170509_Italy.pdf

Student Questions

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❑ https://en.wikipedia.org/wiki/Device-to-device
❑ https://en.wikipedia.org/wiki/Laa
❑ https://en.wikipedia.org/wiki/LTE-WLAN_Aggregation
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Student Questions

Acronyms

- 3GPP   Third Generation Partnership Project
- AAS   Active Antenna System
- BPSK   Binary Phase Shift Keying
- CA   Carrier Aggregation
- CDN   Content Distribution Networks
- cDRX   Continuous Mode DRX
- CoMP   Coordinated Multi-Point Operation
- dB   deciBel
- DC   Dual Connectivity
- DL   Downlink
- DMRS   Demodulation Reference Signal
- DRX   Discontinuous Reception
- eICIC   Enhanced Inter-Cell Interference Cancellation
- eIMTA   Enhanced Interference Mitigation and Traffic Adaptation
- eLAA   Enhanced License Assisted Access
- eLWA   Enhanced LTE/WLAN Aggregation

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Acronyms (Cont)

- eLWIP   Enhanced LTE/WLAN over IP Tunnel
- eMBB   Enhanced Mobile Broadband
- eMBMS   Enhanced Multicast Broadcast Multimedia Service
- eMTC   Enchanded Machine Type Communication
- eNB   Evolved Node-B
- EPDCCH   Enhanced Phyiscal Downlink Control Channel
- EPS
- FCC   Federal Communications Commission
- FD   Full Dimension
- GHz   Giga Hertz
- GNSS   Global Navigation Satellite Systems
- HARQ   Hybrid Automatic Repeat Request
- HTTP   Hyper-text Transfer Protocol
- ICS   IMS Centralized Services
- ID   Identifier
- IMS   Internet Multimedia System

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Acronyms (Cont)

- IoT   Internet of Things
- IP   Internet Protocol
- ISBN   International Standard Book Number
- IUA   ICS User Agent
- kHz   Kilo Hertz
- LAA   License Assisted Access
- LAN   Local Area Network
- LTE   Long-Term Evolution
- LWA   LTE/WLAN Aggregation
- LWIP   LTE/WLAN over IPSec Tunnel
- MBMS   Multimedia Broadcast Multicast Service
- MBS   Metropolitan Beacon System
- MCCH   Multicast Control Channel
- MHz   Mega Hertz
- MIMO   Multiple Input Multiple Output
- MPD   Media Presentation Description

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Acronyms (Cont)

- MTC — Machine Type Communication
- MUST — Multi-User Superposition Transmission
- mW — milliWatt
- NAICS — Network Assisted Interference Cancellation and Supression
- NB — Narrow-Band
- NOMA — Non-Orthogonal Multiple Access
- NR — New Radio
- PC5 — One of LTE V2X Interfaces
- PDN — Public Data Network
- PDSCH — Physical Downlink Shared channel
- PHY — Physical
- PLMN — Public Land Mobile Network
- PRB — Physical Resource Block
- PROSE — Proximity Services
- PSD — Power Spectral Density
- PSM — Power save mode

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Acronyms (Cont)

- PTM   Point-to-Multipoint
- QAM   Quadrature Amplitude Modulation
- QoS   Quality of Service
- QPSK   Quadrature Phase Shift Keying
- RAN   Radio Access Network
- RF   Radio Frequency
- RS   Reference Signal
- SC-PTM   Single-Cell Point-to-Multipoint
- SON   Self-Organizing Network
- SRS   Sounding Reference Signals
- TDD   Time-Division Duplex
- TTI   Transmit Transition Interval
- UE   User Element
- UL   Uplink
- URL   Uniform Resource Locator
- VANET   Vehicular Area Network

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Acronyms (Cont)

- WAN   Wide-Area Network
- WLAN   Wireless Local Area Network

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Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
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Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

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